College (Sir Felix Schuster, Bart.), the dean of the faculty of science (Prof. Millar Thomson, F.R.S.), the dean of the faculty of medicine (Prof. Sidney Martin, F.R.S.), the chairman of the military education committee (Prof. D. S. Capper), the secretary of the Royal Society (Dr. J. Rose Bradford), the dean of the college faculty of medical sciences (Prof. G. D. Thane), and the Jodrell professor of physiology (Prof. E. H. Starling, F.R.S.).

In his address, given to an audience which filled the lecture theatre, Mr. Haldane outlined the gradual growth of the facilities for the highest education in science which has been witnessed in this country during the past twenty years, a growth which, he pointed out, has completely upset the somewhat pessimistic prognostications of Matthew Arnold, who, as an authority on this question, expressed the opinion that any extension of the facilities offered by the older universities was most improbable. It is, however, only fair to state that it was with reference to the arts rather than the science side of education that he took this somewhat gloomy view of affairs. Mr. Haldane, who admitted that he appeared to others to be obsessed with a passion for organisation, while avoiding some of those debatable questions which were so intimately bound up with the work of many of those who listened to him, indicated with exceptional lucidity that if any civilised country is to continue to hold its own, abundant facilities must exist for the pursuit of knowledge by research, and that it was unnecessary to support this by arguments must have been apparent to his audience. That in the institute of physiology full provision for the highest teaching in this subject is available, not only for our own countrymen, but for those from American and foreign universities, was also indicated by Prof. Starling, who, after speaking of the international bonds of friendship which the study of science does so much to foster, made clear the truism that in such places as this institute the real work is carried out which supplies the medical profession throughout the world with the knowledge requisite for their successful treatment of disease. Those who have the best interests of their profession at heart know that this is so.

The erection of this institute is largely due to Prof. Starling, whose ideas have been carried out in this building, which, with its admirable arrangements for work and excellent equipment, forms a great addition to the opportunities for teaching and research offered by the University of London.

THE INVESTIGATION OF GASEOUS EXPLOSIONS.[1]

AT the Leicester meeting (1907) of the British Association it was suggested that the investigation of gaseous explosions was a matter which might suitably form the work of a committee of Section G (Engineering), and although the subject is chiefly of interest to engineers because of its bearing on the theory of the internal-combustion engine, the committee appointed has not confined its attention to questions of a purely practical character, but has discussed many questions of scientific importance which might properly be considered of interest to the physical and chemical sections.

In order that the labours of the committee might lead to some result within a reasonable time, the work so far undertaken has been mainly a critical examination and discussion of the results of previous investigations with a view to further research, and to this end the report discusses, at some length, various interesting and important matters which in their opinion require further investigation.

The essential feature in the operation of an internal-combustion engine is the explosion of a mixture of inflammable gases by which is formed a complex mixture of nitrogen, carbon dioxide, steam and oxygen, and the performance of the engine depends primarily on the changes of pressure and volume of the gas, and is only influenced in a slight degree by the nature of the chemical changes and the velocity with which these take place.

The problem is mainly that of the behaviour of gases at high temperatures, and the properties of such gases are completely defined when the relation between pressure and volume at constant temperature is known, and the internal energy is given as a function of the temperature and the density. The first relation is substantially that expressed by Boyle's law for all gases with which we have to deal, while it is sufficient for the present if the internal energy can be expressed as a function of the temperature, and it is with this internal-energy function that the report chiefly deals.

Measurements of the internal energy have been carried out, as a rule, with the gas at either constant pressure or at constant volume, and the experiments of Holborn and Austin and Holborn and Henning on air, steam, and CO_2, at constant pressure, have shown that, with increasing temperature, there is an increase in the internal energy, which is probably not a linear function of the temperature. The principal part of our knowledge of the behaviour of gases at high temperatures has, however, been obtained by explosion experiments in closed vessels, and if we could accurately make the necessary corrections for deducing from the observed pressures in a real explosion the pressures reached in an ideal one, we could obtain an accurate value of the internal-energy function.

The difficulties of making corrections due to the disturbing influences are very great, but in spite of this the study of explosion pressures has been mainly responsible for the knowledge we possess of the energy function, and the committee therefore considers this method and the possible inaccuracies in detail.

If the calorific value of a mixture before combustion is known, and the heat lost at any time after the explosion is determinate, the remaining disturbing causes are due to the want of thermal and chemical equilibrium, and possibly to the motion of the gases; we must therefore determine what effect all these disturbing factors have in altering the observed pressure from which the temperature is inferred.

Much of the loss of heat appears to be due to direct conduction to the walls of the enclosing vessel, but it is probable that loss by radiation is also important, as in some of the experiments considered, where loss by conduction was improbable, the pressures obtained were consistent with a considerable loss by radiation.

The thermal state of the exploded charge has been the subject of much investigation. In a closed vessel the combustion at the point of ignition is completed before any appreciable rise of pressure takes place, and the flame spreads outwards at a velocity which has been estimated at from 120 to 150 centimetres per second, accompanied by a rise of pressure due to the progress of the combustion. The flame, therefore, spreads in an increasingly denser gas, and since the rise of temperature on explosion is nearly independent of the pressures before ignition, the temperatures attained at those places which are reached last by the flame are much below the mean owing to the final adiabatic compression and consequent rise in temperature of the already ignited gas.

At the moment of maximum pressure the temperature varies enormously, as is shown by the measurements of Hopkinson in an approximately cylindrical vessel of 6 cubic feet capacity, where, with a mean temperature of 1600° C., the maximum temperature at the point of ignition was 1900° C., and near the walls about 1200° C.

The temperature of the wall surface in such a vessel is much lower, and in a gas engine, working under normal conditions with a water-jacketed cylinder, the usual temperature is about 200° C., with a fluctuation of rarely more than 10° C. during the whole cycle. Up to the time of maximum pressure there appears to be no appreciable equalisation of temperature, but convection and conduction rapidly obliterate these initial differences. If the specific heat of the gas were constant, the attainment of thermal equilibrium would make no difference to the

[1] First Report of the British Association Committee appointed for the Investigation of Gaseous Explosions, with Special Reference to Temperature. Presented at the Dublin meeting, 1908.

pressure, but, owing to variation of specific heat with temperature, a correction must be made, which in the present state of knowledge is very uncertain, as the distribution of temperature and the variation of the specific heat are not accurately known.

The condition of the gas as regards chemical equilibrium has been the subject of much speculation and research. Calculations by the pv/τ law of the rise of pressure due to the amount of thermal energy liberated give very much greater pressures than are found by experiment, and various theories have been put forward to account for this.

The view that dissociation of the constituents of the ignited charge will account for the discrepancy appears improbable, as there is no conclusive evidence to show that either steam, CO_2, or nitrogen are split up to any extent at the temperatures and pressures obtained, while the fact that in weak mixtures the discrepancy between calculation and experiment is about the same lends no support to the dissociation theory. The cooling effect of the walls plays some part, but the experimental evidence of explosions in vessels of various forms and capacities shows that this cause alone is quite insufficient to account for the difference.

Another view, due to Clerk, is that the combustion of the gas is not complete at maximum pressure, so that in mixtures of all strengths, but especially in weak ones, there is a suppression of heat which materially affects the maximum explosion pressure, and the cooling effect of the walls will have a considerable time effect on the combustion process. It cannot be doubted that combustion is greatly retarded in the neighbourhood of cold metal walls, and some direct evidence is available that such phenomena are mainly of a surface character. Profs. Bone and Dixon are of the opinion that if the effect of cold bodies may be disregarded, the combustion of the charge in the presence of air is practically complete before the attainment of maximum pressure.

The effect of the explosion is also to set up intense vibratory motion in the gas, but it appears unlikely that this has any effect on the mean pressure shown by the gauge. Although the difficulties which arise in the determination of the internal energy are so great, the results of independent observers are in very fair agreement, as is shown by the accompanying diagram, Fig. 1, in which various determinations of the internal energy of a gas-engine mixture are marked and compared with the values for an ideal gas having an internal energy of 4·9 calories per gram molecule per degree.

The experiments of Clerk are particularly interesting, as he used a method of a novel character, which permitted the study of the working fluid in the gas-engine cylinder itself.

An indicator diagram of a gas-engine cycle gives information as to the time of ignition, the work done, and the compression and expansion of the charge. It is possible by rearranging the valve gear to shut in an exploded charge, and the indicator card obtained while the engine is coming to rest affords further information concerning the specific heat and the rate of heat loss to the walls.

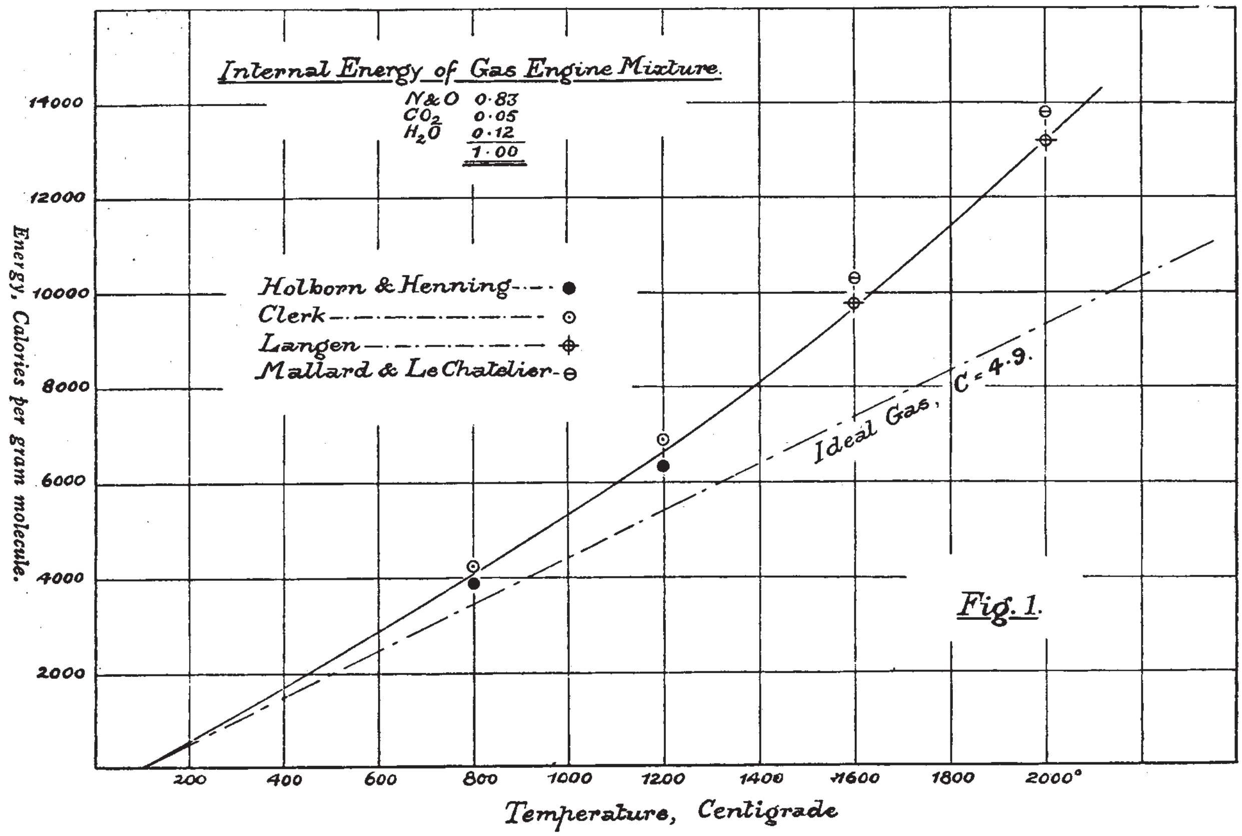

Fig. 1.

A portion of such a diagram is shown in Fig. 2, in which the curve BC represents the first compression of the charge after the valves are shut down, and CD represents the following expansion curve. Usually, the first five or six cycles are distinct, but they ultimately merge into one another as the engine comes to rest. If the gas be compressed or expanded without gain or loss of heat, the specific heat at constant volume can be readily obtained by a consideration of the work areas of the diagram and the end temperatures, but on account of the heat flow to the walls a correction must be made, which can be obtained by a successive approximation process. This heat loss is divided between the expansion and compression, and Mr. Clerk divides it on the assumption that if the mean temperatures in compression and expansion are the same, the heat loss will be the same. The mean tempera-

ture in expansion is rather less than in compression, and therefore the loss is not divided equally between the two.

The results of experiments made in this way give values of the specific heat at constant volume which increase more than 30 per cent. in the range from 100° C. to 1500° C., and tend to a limit at high temperatures, while the observations indicate that this apparent change is accompanied by continued combustion.

Experiments made since the report was issued show that, relative to the mean temperature, the heat loss for air during compression is greater than the loss during expansion; these experiments will be continued to ascertain if such is the case for a gas-engine mixture.

In concluding its discussion of explosion experiments the committee expresses the opinion that "values of the energy obtained from explosion records are not subject to any very great errors on account of heat loss by conduction to the walls of the vessel, or on account of incomplete combustion, but that they are affected by errors of quite unknown amount due, first, to heat radiated, and, secondly, to the want of thermal equilibrium at the time when the pressure is measured. For the purpose of testing the first of these conclusions it is very desirable that further experiments should be made on explosions in vessels of greatly different size, but of similar form. The opinion entertained by the committee that incomplete combustion is a surface-phenomenon, on which this conclusion

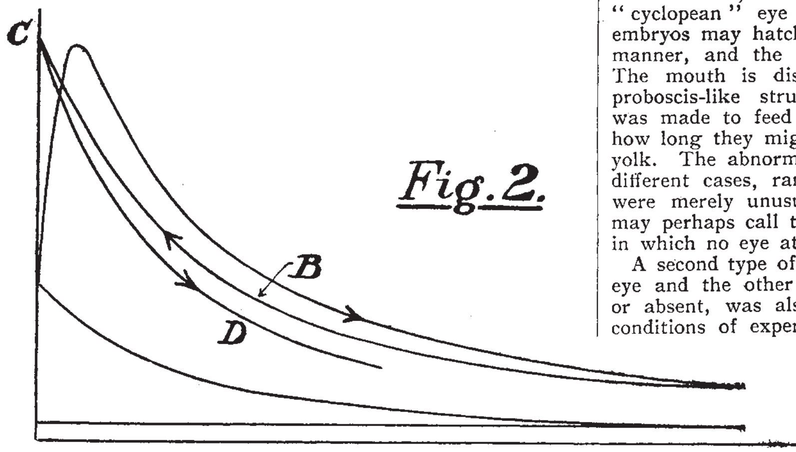

Fig. 2.

as to the validity of the method is based, also requires further confirmation. As regards the second conclusion, further experiment on the actual amount of heat radiated by burning gas is urgently required, and also experiments to confirm or negative the effect of the nature of the wall surface upon the pressure reached in an explosion. The effect of want of thermal equilibrium can be determined up to a point by calculation; but before such calculation can be usefully made, it is desirable that further information should be obtained as to the temperature distribution after an explosion, especially in the neighbourhood of the walls."

In view of the importance of measurements of temperature in connection with gas explosions, the committee considers it desirable that the relations between pressure, volume, and temperature of gas thermometers should be determined at very high temperatures. The nitrogen thermometer has been used with an iridium bulb up to 1600° C., but no other gas has been tested beyond 1100° C. The chief difficulties in carrying out comparisons of gas thermometers have been the absence of any material which is impervious to the gas and sufficiently refractory to withstand very high temperatures. Dr. Harker believes that he is now in possession of a material suitable for gas thermometry up to 1800° C., and he has suggested that an attempt be made to compare thermometers using nitrogen and argon at the highest temperatures possible. If they agree, the probability is in favour of both being in substantial agreement with the thermodynamic scale, but if it is found that they differ, the presumption will be that the argon thermometer is in closer agreement with the thermodynamic scale, as this gas is supposed to be monatomic and incapable of dissociation. The committee hopes that it will be possible to carry on a research of this kind, and that the resources of the National Physical Laboratory will be available for the inquiry.

The report concludes with a note by Prof. Callendar, printed in full as an appendix, and containing a critical examination of the experimental work on "the deviations of actual gases from the ideal state, and on experimental errors in the determinations of their specific heats."

E. G. COKER.

"CHEMICAL" EMBRYOS.

SOME very remarkable observations have been made from time to time during the last twenty years on the effect of chemical stimuli in bringing about abnormalities in developing embryos. The "Lithium larvæ" of the sea-urchin and of the frog, obtained by Herbst and Morgan, are familiar examples of this class of phenomena, but perhaps the most remarkable is the "Magnesium embryo" of the fish, *Fundulus heteroclitus*, described by Charles R. Stockard in the February number of the *Journal of Experimental Zoology*. A large percentage of the embryos of this fish, when subjected during their development to the influence of magnesium salts dissolved in sea-water, are found to possess a single median or "cyclopean" eye in place of the ordinary pair. These embryos may hatch and swim about in a perfectly normal manner, and the single eye is evidently fully functional. The mouth is displaced ventrally, and gives rise to a proboscis-like structure, but, unfortunately, no attempt was made to feed the embryos, so that we do not know how long they might live after the absorption of the food-yolk. The abnormality was present in varying degrees in different cases, ranging from embryos in which the eyes were merely unusually close together, through what we may perhaps call the typical cyclopean condition, to others in which no eye at all was developed.

A second type of monster, with one perfect asymmetrical eye and the other eye of the normal pair either reduced or absent, was also frequently met with under the same conditions of experiment. The author claims that this is the first instance of repeatedly causing, by the use of chemical substances, vertebrate monstrosities such as are known in nature, and his results seem to indicate that the monstrous Cyclops of man and other mammals may not be due to germinal variation, but to some effect of environment during development.

Incidentally, the researches may also throw some light upon another extremely interesting result of recent investigation in the domain of experimental embryology. Several observers, notably Spemann and Lewis, have shown that in amphibian embryos the formation of the lens of the eye appears to be dependent upon stimulation of the superficial epiblast by the developing optic cup. Lewis, for example, has found it possible to transplant the optic cup of a frog embryo, and thereby cause the development of a lens from superficial epiblast quite remote from the normal lens-forming region. Stockard, however, concludes from his researches on Fundulus that lens-formation does not in all cases depend upon a direct stimulus from the optic cup, for his abnormal Fundulus embryos sometimes showed a supernumerary lens developing without any relation to an optic cup.

Why the presence of magnesium salts should cause abnormal eye-development is one of the numerous mysteries of biology which seem likely to remain unsolved for a long time to come. Experimental embryology is still in its infancy, and it is too soon to expect any adequate explanation of such phenomena, but we are beginning to realise that the nature of the environment counts for a very great deal in determining the course of individual development. The most encouraging feature of modern biology is, undoubtedly, the adoption of experimental methods, and such methods bid fair to be as productive in this branch of science as they have already been in chemistry and physics. It would probably be too